Introduction

Changes in the application of global quotas and other WTO inspired market liberalization measures in the textiles and clothing trade over the past decade have resulted in major restructuring of textile manufacturing in many countries. These countries have had to face the fact that they must become more competitive and more innovative in future in order to survive. This in turn has led to an increasing emphasis on new ‘higher value’ market opportunities, involving more technically sophisticated and innovative products.

Australia is no stranger to this situation. This paper presents one example of how Australia’s textile industry is dealing with the transition from being a producer of traditional commodity type textiles to that of niche, high value, special performance textile manufacturing. This discusses the market for medical textiles, now emerging as one of the major growth opportunities for the textile industry.

The Australian Textile Industry Profile

To place this transformation into context, the following table sets out the magnitude of changes in production of ‘traditional’ textiles which have occurred in Australia over the past decade.

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<thead>
<tr>
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<tbody>
<tr>
<td>Scoured &amp; carbo wool</td>
<td>(kt)</td>
<td>118.6</td>
<td>53.3</td>
</tr>
<tr>
<td>Wool &amp; Man-made fibre tops</td>
<td>(kt)</td>
<td>55.3</td>
<td>4.6</td>
</tr>
<tr>
<td>Wool yarn</td>
<td>(kt)</td>
<td>19</td>
<td>8.1</td>
</tr>
<tr>
<td>Cotton yarn</td>
<td></td>
<td>33.4</td>
<td>Not Published</td>
</tr>
<tr>
<td>Wool fabric</td>
<td>(’000 sq m)</td>
<td>5,427</td>
<td>1,362</td>
</tr>
<tr>
<td>Cotton fabric</td>
<td>(’000 sq m)</td>
<td>47,230</td>
<td>8,046</td>
</tr>
<tr>
<td>Polyester/blended fabrics &lt; 85% man-made</td>
<td>(’000 sq m)</td>
<td>32,462</td>
<td>6,360</td>
</tr>
<tr>
<td>Polyester/blended fabrics &gt; 85% man-made</td>
<td>(’000 sq m)</td>
<td>10,428</td>
<td>5,391</td>
</tr>
<tr>
<td>Other Man-made fabrics</td>
<td>(’000 sq m)</td>
<td>90,876</td>
<td>4,827</td>
</tr>
<tr>
<td>Total woven fabrics</td>
<td>(’000 sq m)</td>
<td>186,424</td>
<td>25,986</td>
</tr>
<tr>
<td>Knitted fabrics</td>
<td>(kt)</td>
<td>14.1</td>
<td>5.2</td>
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However, this decline in traditional textile manufacturing should not have come as a surprise to the Australian textile sector. A Werner International report to an Australian TCF&L Market Access Study in 2003\(^1\) noted the following in assessing Australia’s future trade prospects in the field of traditional textile and garment manufacturing:

‘It is clear that no developed economy, even countries that have been consolidating their position in the international market…can escape the contraction in local textile and garment production. Further trade liberalization will only accelerate the decline of local apparel production. Australia is no exception to this’.

Australia has experienced the full impact of changes in its textile trade following dismantling of most of its border protection measures over a decade ago. This has resulted in major rationalisation and with it, many mill closures. It should be noted that not all of the blame for the demise of these firms should be sheeted home to the more open market access policies of government. Many textile companies extracted large profits behind high levels of protection established after the Second World War and which continued into the 60’s and 70’s. Unfortunately, few firms saw the need to improve their competitive performance and increase focus on the development of new products. This resulted in only relatively small proportions of company profits being invested in new technology, R&O and skills development.

Once the comfort afforded by market protection was removed, it was no surprise that many of these textile firms didn’t survive.

**Australia’s changing textile landscape**

It would be reasonable to conclude on the basis of the figures presented above that Australia’s textile industry has all but disappeared. The reality is however, somewhat different. There is now a growing shift towards technical textiles, industrial textiles, special performance textile products and generally, more technology intensive textile manufacturing.

Large integrated manufacturing operations, particularly those which previously focused on commodity textiles have all but disappeared in the face of a surge in imports from low cost manufacturing countries such as China and India. Low labour cost countries now account for over 50% of Australia’s textile and clothing market.

The Australian textile industry has responded to this increased competition with an increasing focus on smaller, more flexible, design and technology driven companies. These companies are behind the emergence of a ‘new’ textile industry, with an emphasis on higher value, innovative products and processes. However, these developments are also demanding new and higher level technical skills and knowledge. This is leading to much closer collaboration between research, education and industry organisations.

It is in this area that the International Fibre Centre plays a role. Established in 1998 by the Victorian State Government (recognizing the State’s position as the major centre for textile manufacturing in Australia), the IFC assists technology transfer, education and skills development in the fibre and textile industries. As part of this role, the IFC has worked closely with the Centre for Material and Fibre Innovation at Deakin University’s Geelong Technology Precinct. IFC commissioned the Centre to undertake research into new areas of potential market opportunity for textiles, including nanotechnology in fibres and textiles, functional and smart textiles and medical applications for textiles. The international market for innovative products based on these technologies is estimated at billions of dollars and is expected to grow rapidly in future.

The following case study focusing on medical textiles represents one of those areas of market opportunity.

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\(^1\) Werner International report to the TCF&L Market Access Study in 2003 p9
Medical Applications of Fibres and Textiles

The term **medical textiles** has been defined by Fisher (2006) as ‘fibre-based products and structures used in first aid or the clinical treatment of a wound or medical condition’. Applications include: protective and health care textiles, such as surgical gowns; external devices, such as wound dressings and orthopaedic bandages; implantable materials, such as surgical sutures and vascular grafts; extracorporeal devices, including blood filters and artificial kidneys; and dental products, such as toothbrush filaments.

**Hygiene textiles**, on the other hand, are described by Fisher (2006) as those that ‘deal with the absorption of bodily waste products, specifically urine, faeces and menstrual discharge’. These include nonwovens for use in disposable baby diapers, feminine hygiene products and adult incontinence products. Fisher makes the further point that medical textiles and disposable hygiene products are produced in different sectors of the industry, with the majority of companies manufacturing one class of product or the other.

Notwithstanding this distinction between medical and hygiene textiles, the **Medtech** application area of technical textiles, as defined by David Rigby Associates (2000), encompasses all textile materials (including consumer products) used in health and hygiene applications. It is this broader definition of medical textiles which is generally used (unless indicated otherwise) throughout this paper. Both natural and man-made fibres are used to manufacture medical textiles, and fibre selection depends on the particular end-use properties required.

Fisher (2006) reports that the global healthcare market is experiencing buoyant growth, with strong, long-term demand for health-related products and services. Global demand will continue to rise as populations increase in developing countries, and as populations age in developed countries. Fisher believes that the medical/hygiene textiles sector is a niche market dominated by a small number of large suppliers, and as such should be viewed as a component of the healthcare industry, rather than as an inherent part of the textile sector.

**The global healthcare market**

Healthcare is now one of the world’s largest industries, with an estimated value of US$3.5–4 trillion per year. Global demand for healthcare services is rapidly rising as populations increase in developing countries, and as populations age in developed countries. In 2004, the world market for **medical consumer goods** was valued at US$220 million. The US dominates this market with sales of US$95 billion, followed by Europe with sales of US$65 billion. The global market for **hygiene products** is valued at approximately US$73 million (manufacturing costs, not retail value); with 33% of this in North America, and 30% in Europe. This industry is based largely on oil-based by-products, where both price and demand are highly volatile (Fisher 2006).

**Fibres and manufacturing methods**

Fibres used in medical applications have been classified by Rigby and Anand (2000) as natural or synthetic, and biodegradable or non-biodegradable: ‘It is critical that these fibres are non-toxic, non-allergenic and non-carcinogenic, and that they can be sterilised without altering physical or chemical properties.’

Natural fibres such as cotton, silk and regenerated cellulose (e.g. viscose rayon) are widely used in non-implantable materials and healthcare/hygiene products (Rigby & Anand 2000). Commonly used synthetic materials include polyester, polyamide, polytetrafluoroethylene (PTFE), polypropylene, carbon and glass. Biodegradable fibres include cotton, viscose rayon, polyamide, polyurethane, collagen and alginate, and are absorbed by the body within two to
three months after implantation. Non-biodegradable fibres include polyester, polypropylene, PTFE and carbon, and these take more than six months to be broken down by the body.

The following natural polymers (Rigby & Anand 2000) are important materials for wound dressings:

- Collagen: obtained from bovine skin
- Alginate: produced from seaweed
- Chitin: obtained from crab and shrimp shells
- Chitosan: produced from treatment of chitin with alkali.

Collagen fibres are used as sutures, and are as strong as silk. Dressings containing calcium alginate fibres are haemostatic (i.e. stop bleeding) and are effective in the treatment of a wide variety of wounds. Chitin possesses antithrombogenic characteristics (i.e. inhibits the formation or development of blood clots). Chitin non-woven fabrics are used as artificial skin to facilitate the healing process. Synthetic fibres with important medical applications include polycaprolactone (PCL) and polypropiolactone (PPL). Man-made fibres based on lactic acid have similar strength and heat properties to nylon, and are also biodegradable. Microbiocidal compositions that inhibit the growth of micro-organisms can be applied as coatings natural fibres, or can be incorporated directly into synthetic fibres.

Fisher (2006) has classified the manufacturing processes used for medical and hygiene textiles as follows:

- Extruded polymers: used as filaments or tapes (or further processed)
- Braided textiles: sutures; replace tendons and ligaments
- Wovens and knitteds: bandages, vascular grafts, hernia meshes
- Hollow fibres: blood filters
- Nonwovens: wound dressings, disposable hygiene products, protective clothing.

Nonimplantable materials [Rigby and Anand (2000)]

Rigby and Anand (2000) have defined nonimplantable materials as those materials that are 'are used for external applications on the body and may or may not make contact with skin'. Table 1 illustrates the range of textile materials employed within this category, the fibres used, and the principal method of manufacture.

**Wound dressings** are to provide protection against infection, absorb blood and exudate, promote healing and, in some instances, apply medication to the wound. Generally composite materials are used: an absorbent layer is held between a wound contact layer and a flexible base material. The absorbent pad absorbs blood or liquids and protects the wound. The wound contact layer should prevent adherence of the dressing to the wound and be easily removed without disturbing new tissue growth. Base materials are normally coated with an acrylic adhesive to provide the means by which the dressing is applied to the wound. The use of natural fibres can contribute significantly to the healing process.

Other textile materials used for wound dressing applications include gauze, lint, and wadding. Gauze is an open weave, absorbent fabric that when coated with paraffin wax is used for the treatment of burns and scalds. In surgical applications gauze serves as an absorbent material when used in pad form (swabs); yarns containing barium sulphate are incorporated so that the swab is X-ray detectable; Lint is a plain weave cotton fabric that is used as a protective dressing for first-aid and mild burn applications. Wadding is a highly absorbent material that is covered with a nonwoven fabric to prevent wound adhesion or fibre loss.
Nanofibre structures are ideal for wound dressings, due to their: large surface areas; controlled pore-size; controlled wettability; controlled swelling; and controlled absorption (by the body) (Růžičková 2006).

**Bandages**

Bandages are designed to perform a whole variety of specific functions depending upon the final medical requirement. They can be woven, knitted or nonwoven, and are either elastic or non-elastic. The most common application for bandages is to hold dressings in place over wounds. Such bandages include lightweight knitted or simple open weave fabrics made from cotton or viscose that are cut into strips then scoured, bleached and sterilised. Elasticated yarns are incorporated into the fabric structure to impart support and conforming characteristics.

Knitted bandages can be produced in tubular form in varying diameters on either warp or weft knitting machines. Woven light support bandages are used in the management of sprains or strains and the elasticated properties are obtained using cotton crepe yarns. Similar properties can also be achieved by weaving two warps together, one beam under a normal tension and the other under a high tension. When applied under sufficient tension, the stretch and recovery properties of the bandage provide support for the sprained limb.

Compression bandages are used for the treatment and prevention of deep vein thrombosis, leg ulceration and varicose veins, and are designed to exert a required amount of compression on the leg when applied at a constant tension. Compression bandages are classified by the amount of compression they can exert at the ankle and include extra-high, high, moderate and light compression, and can be either woven and contain cotton and elastomeric yarns or warp and weft knitted in both tubular or fully fashioned forms.

Orthopaedic cushion bandages are used under plaster casts and compression bandages to provide padding and prevent discomfort. Nonwoven orthopaedic cushion bandages may be produced from polyurethane foams, polyester or polypropylene fibres, and contain natural or other synthetic fibres. Nonwoven bandages are lightly needle-punched to maintain bulk and loft.

**Extracorporeal devices**

Extracorporeal devices are mechanical organs that are used for blood purification and include the artificial kidney (dialyser), artificial liver and mechanical lung (Rigby & Anand 2000). The functions of these devices, and the fibres involved, are given in Table 1.

<table>
<thead>
<tr>
<th>Product application</th>
<th>Fibre type</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Artificial kidney</td>
<td>Hollow viscose, hollow polyester</td>
<td>Remove waste products from patient's blood.</td>
</tr>
<tr>
<td>Artificial liver</td>
<td>Hollow viscose</td>
<td>Separate and dispose patient's plasma, and supply fresh plasma.</td>
</tr>
<tr>
<td>Mechanical lung</td>
<td>Hollow polypropylene, hollow silicone, silicone membrane</td>
<td>Remove carbon dioxide from patient's blood, and supply fresh blood.</td>
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</table>

(Rigby & Anand 2000, p. 417)

The application of an artificial kidney is often referred to as hemodialysis (The Kidney Transplant/Dialysis Association n.d.). The most common artificial kidney is the hollow fibre...
dialyser, a cylinder containing a bundle of thousands of tiny, hollow, cellophane-like fibres through which a patient’s blood passes in one direction. Dialysate circulates around and between the fibres.

Cellophane is a sheet-like material made from regenerated cellulose (Kidney Transplant/Dialysis Association n.d.). It is a semipermeable membrane, which contains microscopic holes or pores through which particles of only small molecular size may pass. Normal blood is made up of:

- water (90%)
- red and white cells
- protein, fat, sugar and minerals (called electrolytes, such as sodium, potassium, calcium, magnesium chloride, bicarbonate and phosphate)
- waste products (such as urea, creatinine and uric acid).

During dialysis, waste products pass through the membrane into the dialysate, which is refreshed either periodically or constantly; this keeps the concentration of waste products in the dialysate low, and effects their permanent removal from the blood. The red and white cells, as well as the fat and protein molecules, are too large to pass through the membrane. Electrolytes (as well as water)—because of their small molecular size—are able to pass freely in both directions through the membrane. The concentration of the various electrolytes in blood must be maintained within narrow limits, and it is critical to adjust the concentrations of electrolytes in the dialysate to the same levels in normal human blood serum so that there is no net flow in either direction.

**Implantable materials (I)**

Implantable products range from sutures to vascular grafts and artificial ligaments. Key issues (Rigby & Anand 2000) for implants are as follows:

- **Biocompatibility**: This is major importance to ensure that the material is not rejected by the body.
- **Porosity**: This determines the rate at which human tissue will grow and encapsulate the implant.
- **Small circular fibres** are better encapsulated with human tissue than larger fibres with irregular cross-sections.
- **Toxic substances** must not be released by the fibre polymer, and the fibres should be free from surface contaminants such as lubricants and sizing agents.
- **Biodegradability**: Polyamide is the most reactive material, losing its overall strength after only two years. PTFE is the least reactive material.

**Sutures** for wound closure are manufactured from monofilament or multifilament threads (Rigby & Anand 2000). Biodegradable sutures are used mainly for internal wound closures, and non biodegradable sutures are used in situations where they can be removed when the wound is healed sufficiently.

Tying of knots in conventional sutures leads to stress concentration at the knot, resulting in tissue distortion and inflammation. Ingle and King (2006) have developed a technique for producing barbed sutures (Figure 1), and these have been found to produce minimal scarring after cosmetic surgery.
The strength and flexibility textile materials make them suitable for soft-tissue implants for the replacement of tendons, ligaments and cartilage in both reconstructive and corrective surgery (Rigby & Anand 2000).

Artificial tendons are woven or braided porous meshes or tapes surrounded by a silicone sheath. Braided polyester artificial ligaments are strong and exhibit resistance to creep from cyclic loads. Braided composite materials containing carbon and polyester filaments have also been found to be particularly suitable for knee ligament replacement. Low density polyethylene resembles natural cartilage, and is used to replace facial, nose, ear and throat cartilage. Carbon fibre-reinforced composite structures are used to resurface the defective areas of articular cartilage within synovial joints (e.g. the knee) as a result of osteoarthritis.

Orthopaedic implants are used for hard tissue applications to replace bones and joints (Rigby & Anand 2000). Fibre-reinforced composite materials are replacing metal implants for this purpose. Nonwoven mats, which acts as an interface between the implant and the adjacent tissue, are used to promote tissue ingrowth. Braided surgical cables composed of steel filaments ranging from 13–130 microns are used to stabilise fractured bones or to secure orthopaedic implants to the skeleton.

Vascular grafts, manufactured using polyester of PTFE woven or knitted structures, are used in surgery to replace damaged thick arteries or veins (Figure 2 (Rigby & Anand 2000). Straight or branched grafts are possible by using either weft or warp knitting technology. Polyester vascular grafts can be heat set into a crimped configuration that improves the handling characteristics. During implantation, the surgeon can bend and adjust the length of the graft, which, owing to the crimp, allows the graft to retain its circular cross-section. Knitted vascular grafts have a porous structure that allows the graft to become encapsulated with new tissue but the porosity can be disadvantageous since blood leakage (haemorrhage) can occur through the interstices directly after implantation. This effect can be reduced by using woven grafts, but the lower porosity of these grafts hinders tissue ingrowth. In addition, woven grafts tend to be stiffer than knitted ‘equivalents’.

The cardiac support device shown in Figure 3 is a mesh sack manufactured from warped knitted polyester. It is used to prevent enlargement of the heart for patients with degenerative heart failure.
Figure 2  Vascular prosthesis (Photo by X Wang, Deakin University; vascular prosthesis by Boston Scientific Corporation 2006)

Figure 3  Cardiac support device (Photo by X Wang, Deakin University; cardiac support device by Acorn Cardiovascular, Inc. 2006)
Implantable materials (II) – scaffold for tissue engineering

According to Ramakrishna (2001), the profound differences between synthetic biomaterial implants and the living tissues of the human body can lead to problems such as infection, loosening, failure and finally rejection. On the other hand, transplantation (transfer of a tissue from one body to another, or from one location in a body to another) is not always practical due to a shortage of donor tissue, as well as the risk of rejection and disease transfer. Hence, there is a need to develop biological substitutes (living or vital materials) to avoid these problems.

Tissue engineering ‘combines mammalian cells and certain synthetic biodegradable materials (materials that eventually disappear after being introduced into a living tissue or organism) to produce living (vital) synthetic tissue substitutes or replacement tissues’ (Ramakrishna 2001).

It is envisaged that tissue substitutes will merge seamlessly with the surrounding host tissue, eliminating problems associated with contemporary biomaterials and transplantation. Considerable research is being carried out globally to produce engineered skin, cartilage, nerve, heart valve and blood vessels. Eventually, it may even be possible to construct entire replacement organs such as the liver and bladder.

Some of the major features of an ideal scaffold system (Ramakrishna 2001) are:

- The material used for the scaffold should be: (i) biocompatible; (ii) ultra-pure; and (iii) able to formed reproducibly—at both the microscopic and macroscopic levels—into a variety of sizes and structures.
- The scaffold needs to be manufactured from biodegradable material that maintains its volume, structure and mechanical stability long enough to allow adequate formation of tissue inside the scaffold. None of the degradation products should lead to inflammation or toxicity.
- In order to facilitate cell-surface interaction, scaffolds must: (i) have a high surface-area to volume ratio; (ii) have controlled interconnected pore structures, pore size distribution and pore geometry; and (iii) be able to retain their shape and structure under electromechnical conditions.
- The flexibility of a scaffold should be close to that of its surrounding tissue, so that once vascularisation starts, no extreme change in the mechanical properties between the host tissue and the scaffold will be experienced by the ingrowing tissue.

A combination of various factors, including: (i) scaffold material; (ii) structure; (iii) physical, chemical (especially surface), mechanical and biological properties; (iv) cell types; and (v) in vitro or in vivo conditions, determine the success of tissue engineering.

The different scaffold materials used in tissue engineering can be grouped into natural and synthetic materials. Collagen, chitin and starch are examples of natural materials that are isolated from human, animal or plant tissues; they typically result in high costs and large batch-to-batch variations, exhibit a very limited range of properties and are often difficult to process.

Synthetic materials are classified as degradable or non-degradable types. Non-degradable materials include polyethylene, polyethyleneterephthalate and PTFE. Synthetic biodegradable polymers, such as PGA and PLA, polyanhydrides and polyoesters offer control over structure and properties, as well as degradation times, and have been widely investigated in tissue engineering research. Polyester-based materials dominate the tissue engineering applications of the biodegradable polymers.
Cells are totally dependent on some sort of substrate for their proliferation. There is no universal textile scaffold that meets all the requirements of various tissues. The optimum design of a scaffold for a specific tissue application requires consideration of microstructural, chemical and biological aspects, which are often difficult to isolate as they are interdependent and sometimes have unknown effects.

The microstructural aspects of scaffolds include the size and size distribution, porosity and connectivity of the pores. These aspects provide the optimal spatial and nutritional conditions for the cells, and determine the successful integration of the natural tissue and the scaffold.

The size and alignment of pores in a scaffold has been shown to have a large influence on the amount and rate of vascular and connective tissue growth. The interconnectivity of pores determines the transport of nutrients and waste. The reproducibility of scaffolds is also very important as it determines the dimensional stability of the scaffold as well as the consistency of the tissue formation.

The mechanical aspects of scaffolds, such as structural stability, stiffness and strength, have considerable influence on cellular activity. Cell shape modification takes place as a result of forces both external (including gravity) and internal, and is influenced by the nature (constant or cyclic), type (uniaxial, biaxial, multiaxial and so on) and magnitude of the mechanical stimulation. The mechanical stimulation also affects the release of soluble signalling factors and the deposition of extracellular matrix constituents.

In bone tissue engineering, scaffolds are designed to withstand severe physiological loads. In blood vessel applications, the scaffold needs to be strong enough to withstand physiologically relevant pulsatile pressures and at the same time match the compliance or elasticity values of a native blood vessel. The mechanical aspects of various scaffolds are compared in Table 6. Woven fabrics are relatively rigid, and are used for engineering of bone and acetabular cups. Knits display considerable deformability, and are suitable for bladder and blood vessel tissue engineering applications.

Fibre- and textile-reinforced composites in medicine [Ellis (2005)].

Splinting materials for the repair of broken bones are the oldest and largest medical market for textile-reinforced composites. The use of textile materials overcomes brittleness problems associated with plaster of Paris.

The requirements for a splinting material are a high degree of stiffness, conformability and an open construction to allow for impregnation with a large quantity of plaster. These requirements can conveniently be met by a leno woven construction where the warp yarns cross over one another, locking the weft into place (Figure 21). Such a fabric is also less inclined to fray when cut.

Similar characteristics can also be obtained with various warp knitted and some weft knitted constructions. A number of fibres have been used in conjunction with plaster, particularly cotton, although modern bandages on the market contain combinations of elastomeric yarn and polypropylene, polypropylene, polyester and even glass. Glass has fallen into disfavour, particularly because of the presence of glass dust produced during cast removal.

Walking support frames provide vertical support for patients who have dysfunctional lower limbs. In comparison with a metallic frame, the reductions in both weight and volume—combined with increased rigidity—of a carbon fibre reinforced orthosis have led to marked improvements in walking capability. Although carbon-based materials have brittle failure characteristics, the mode of failure of such devices is of progressive collapse and is therefore inherently safe. Thermoset resin-based materials cannot readily be bent into shape to fit a patient, and so the use of composites in smaller orthoses (such as knee braces) is limited.
In orthopaedic surgery, **bone plates** and screws are often used to treat fractures, particularly of the long bones, and are generally manufactured from stainless steel, cobalt chromium and titanium alloys (Figure 22). The elastic modulus of these metals is much higher than the elastic modulus of human bone (110–220 GPa compared with 17–24 GPa for human bone).

Because of this stiffness mismatch, the normal bone healing process is affected. Possible toxic effects (particularly from unreacted monomers) of all implanted polymeric products, combined with the fact that thermoset bone plates cannot easily be bent to shape in the operating theatre, has limited the possibilities for composites.

**Healthcare/hygiene products**

Rigby and Anand (2002) have described the vast range of healthcare and hygiene products as typically being used ‘either in the operating theatre or on the hospital ward for the hygiene, care, and safety of staff and patients’. As discussed above, however, hygiene textiles—for the purposes of this report—also cover the consumer market, and include such items as feminine hygiene products and baby diapers.

**Operating room textiles** include surgeons’ gowns, caps and masks, patient drapes, and cover cloths of various sizes. Disposable nonwoven surgical gowns have been adopted to prevent sources of infection being transferred to the patient from hospital staff. These materials often combine nonwoven materials and polymer films. For example, Ahlstrom market a breathable viral barrier fabric (Ahlstrom BVR™—Figure 4) with the following structure:

- trilaminate polypropylene-based composite material with a breathable film
- *outer* layer provides strength and some fluid resistance
- *inner* layer provides softness
- *middle* layer blocks viruses and bacteria, but is permeable to moisture vapour.

![Figure 4 Ahlstrom (2006) display at ANEX 2006 (Photo by PG Cookson, Deakin University)](image)
Although the primary function of operating room and hospital clothing is a one of protection, it is critical that they are comfortable to wear. Physiological function and wear comfort can be measured and assessed objectively. The Hohenstein Institute has developed physiological evaluation models, based on laboratory tests with a sweating Skin Model, skin sensorial apparatus and a thermal manikin (Umbach 2006).

Surgical masks consist of a very fine middle layer of extra fine glass fibres or synthetic microfibres covered on both sides by either an acrylic bonded parallel-laid or wet-laid nonwoven. The application requirements of such masks demand that they have a high filter capacity, high level of air permeability, and are lightweight and non-allergenic. Disposable surgical caps are usually parallel-laid or spun-laid nonwoven materials based on cellulosic fibres.

Surgical drapes and cover cloths are used in the operating theatre either to cover the patient (drapes) or to cover working areas around the patient (cover cloths). They are made of films backed on either one or both sides with nonwoven fabric. The film is impermeable to bacteria while the nonwoven backing is highly absorbent to both body perspiration and secretions from any wound. Loop-raise warp-knitted polyester fabrics—laminated with PTFE films for air permeability, comfort and resistance to microbiological contaminants—are used for surgical drapes.

**Hospital ward textiles** such as bedding, clothing, mattress covers, incontinence products, cloths and wipes are used on hospital wards for the care and hygiene of patients. Traditional woollen blankets have been replaced with cotton leno woven blankets to reduce the risk of cross-infection—they are made from soft-spun twofold yarns which possess the desirable thermal qualities; they are also durable and can be easily washed and sterilised.

Clothing products, which include articles worn by both nursing staff and patients, have no specific requirements other than comfort and durability and are therefore made from conventional fabrics. In isolation wards and intensive care units, disposable protective clothing is worn to minimise cross infection. These articles are made from composite fabrics consisting of tissue reinforced with a polyester or polypropylene spun-laid web.

Incontinence products for patients are available in both diaper and flat sheet forms, with the latter used as bedding. A number of weft- and warp-knitted pile or fleece fabrics made from polyester are also used as part of a composite material, which includes foam as well as PVC sheets for use as incontinence mats.

Cloths and wipes are made from tissue paper or nonwoven bonded fabrics, which may be soaked with an antiseptic finish. The cloth or wipe may be used to clean wounds or the skin prior to wound dressing application, or to treat rashes or burns.

Surgical hosiery with graduated compression characteristics is used for a number of purposes, ranging from a light support for the limb, to the treatment of venous disorders. Knee and elbow caps, which are normally shaped during knitting on circular machines and may also contain elastomeric threads, are worn for support and compression during physically active sports, or for protection.

Richer Investment Consulting Services (2006) report that there are 13 basic components to a baby’s diaper, and four of these are fibre/textile based:

- **Hydrophobic nonwoven:** This is used as a top sheet for the leg cuffs, and prevents leakage to the outside of the diaper.
- **Hydrophilic nonwoven:** This is the main top sheet. Its surface is in contact with the baby’s skin, and allows liquids to flow into the diaper core. Hydrophilicity is achieved using a surfactant treatment.
• Cellulose: Used in the construction of the pad, this gives integrity and absorbing capacity to the diaper.

• Acquisition and distribution layer: A nonwoven sub layer between the top sheet and absorbent core. This is specially needed when the absorbent core is very thin in order to move liquids quickly into the absorbent core and reduce leakage.

Diaper manufacturing machines are 20–45 metres long, 6–13 metres wide, and have production rates as high as 1000 pieces/minute. It is estimated that 1.4 billion baby diapers are used daily, and that landfill issues will endure for up to 500 years.

Polytrimethylene terephthalate (PTT) fibre is used by Solotex in products such as toothbrush filaments. In comparison with PET, PTT fibre is claimed to have superior softness, durability, wrinkle recovery and dyeability (Solotex 2004). Whereas PET shows 29% recovery from 20% elongation, PTT exhibits 88% recovery. These ‘exceptional elastic characteristics’ are said to be due to the ‘zigzag conformation of [PPTs] crystalline structure’ (Solotex 2004).

Medical sheepskins

Pressure ulcers are preventable adverse events that are both common and costly. A national survey in the US reported a prevalence of 14.8% across 365 acute hospitals. A pressure ulcer of Stage 2 or higher has been calculated to increase patients’ costs by a factor of 2.7, while the annual cost of pressure ulcers to the American healthcare system is estimated at $US3.6 billion (Jolley et al. 2004).

Many types of pressure-relieving support surfaces are available, but a systematic review found that the only surfaces that consistently outperformed the standard hospital mattress in reducing the incidence of pressure ulcers were high-specification foam mattresses. However, the review also stated that most interventional studies of pressure-relieving support surfaces were seriously underpowered or had other methodological flaws.

In the 1960s and ‘70s, sheepskins were reported to help prevent pressure ulcers, but recent reviews have found inconclusive evidence to support their use (Jolley et al. 2004). In 1998, CSIRO introduced a new high-performance medical sheepskin, the Australian Medical Sheepskin. This product has a denser and higher wool pile and can withstand multiple washes at 80°C, representing a significant advance in leather technology. A randomised controlled trial found that use of this sheepskin reduced the incidence of pressure ulcers in 297 elderly orthopaedic patients by 68% (compared with standard practice). These results were extrapolated to a broader hospital population, where it was found that an Australian Medical Sheepskin pressure-relieving support may prevent one new Stage 1 or Stage 2 ulcer every 46 bed-days of use in general hospital patients at low to moderate risk; these results apply when the sheepskin is used for prophylaxis from the time of admission.

Health-monitoring garments

According to Paradis, Loriga and Taccini (2004), the new generation of technological tools, in particular in the field of telecommunications, has taught people to be continuously in touch with each other. This virtual link is revolutionary in the way of feeling, and if coupled with innovative sensing architectures, could be revolutionary also in the way of acting. There is an emerging need to renovate our health management systems. People need to be more and more conscious of their health status, and more interactive with social assistance services. Remote health monitoring will be accepted and used only if the monitoring devices are based on wearable sensing interfaces, are easy to use, and are easily customised.

Bateup has described the evolution of ‘intelligent textiles’ occurring in the following stages:

1. Functional
   – protection against the environment
active moisture management

2. Smart
   – sensing and monitoring changes in the environment
   – some electrical conducting function (conducting textiles)

3. Intelligent
   – react in some way in response to the ‘sensed’ property
   – most likely have electronic function

(Bateup 2005, p. 4)

Smart textiles are likely to have a significant role to play in the medical area. The LifeShirt by VivoMetrics (1999) has had considerable publicity. It consists of an undergarment into which is sewn an array of sensors that enable the monitoring, recording, analysing and interpreting of vital signs. This monitoring can be carried out during normal work and recreation activities.

**Photonic textiles** are best described as textiles containing flexible arrays of LEDs as lighting systems. Applications in cushions, rugs and backpacks are anticipated. Based on this concept, Philips is looking at the development of a baby jaundice sleeping bag (Asvardi 2006). This will be embedded with blue LEDs, which will break down bilirubin.

![Figure 39 Bilirubin breakdown (PG Cookson, Deakin University)](image)

The ability of a textile to mold to body shape will facilitate treatment. A low intensity light therapy is well suited to a treatment in the home environment.

**References**


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